DEVELOPMENT OF THE MEASUREMENT SYSTEM FOR THE ASSEMBLY OF ROTARY AXES IN A TOOL GRINDER

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ABSTRACT

For the precision tool grinding, the geometrical and dimensional errors of ground tools depend on the accuracy of the grinding machine, and the ground tool's features will have influence on the quality of workpieces processed by the tool. Therefore, elimination of error sources will be beneficial for the improvement of the grinding accuracy, and enhancement of products' quality for workpieces. The positioning accuracy in the linear and rotary axis is the basic requirement for a tool grinder. If a rotary axis is driven by worm and worm gear, indexing accuracy of the rotary axis will be determined by the assembly quality of the worm and worm gear. In order to enhance the indexing accuracy of the rotary axis, a measurement system aided for the assembly has been developed to realize the optimal regulation during the assembly processing of the rotary axis. The correlation between the regulation of worm and worm gear and the indexing accuracy has been investigated and error analysis of the rotary axis has been also performed. Distributions of the indexing error can be gained by the experimental analysis. The improvement of indexing precision can be verified by the comparison analysis between the rotary indexing error before and after compensation.

Index Terms - tool grinder, worm and worm gear, rotary axis, indexing precision

1. INTRODUCTION

The precision level of machine tools can be defined as the machine work within two-point position of the maximum displacement error and rotation error [1]. There are various factors affecting the machine tool precision, overall the error can be divided into kinematic error and static error, while the static error contains the geometrical errors. The static errors contribute 70 percents of precision error in the machine tool production process [2]. Therefore, how to reduce the static error is an important issue.

The machine tools need end-mill for cutting processing, while in the tool grinder the wheel is employed for the grinding of end-mills. Development procedure of the precision tool grinder reveals that the grinder is evolved from conventional manual, semi-automatic to current automatic five axis machines. The tool grinder belongs to the group of CNC machine tool, and it has a more complex mechanism, high precision and reliability of advanced mechanical and electrical integration technology products. A key factor for the grinding precision is the accuracy of the linear axis and the rotary axis. Figure 1 shows a 5-axis tool grinder.

In this study, a rotary axis mechanism is driven by worm and worm gear, Bair and Tsay [3, 4] proposed that two different axial modules are used for the grinding wheel and hob cutter to produce the left and right surfaces of the ZK-type dual-lead worm and worm gear surfaces. The generated dual-lead worm and worm gear have teeth of varying thickness. The backlash of a dual-lead worm gear set can be reduced by adjusting the worm's position along its rotational axis.

The goal of this investigation is to develop a real-time measurement system for the assembly of rotary axes. The major components include the mechanical design, the data acquisition system and HMI arrangement etc. During assembly of rotary axis, indexing accuracy measurement can be determinately by this inspection system. The relationship between worm and worm gear and indexing accuracy can be realized by analysis of rotary axis. The enhancement of indexing precision can be verified by analysis between with and without compensation.

2. ASSEMBLY OF WORM AND WORM GEAR

In this study the rotary axis mechanism of tool grinder is driven by worm and worm gear. In the assembly of rotary axis, dual-lead worm and worm gear are employed (Figure 2), which will have the better effect on the spacer adjustment.

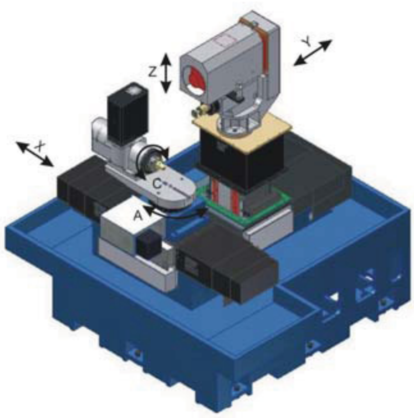

Figure 1 Scheme of a 5-axis tool grinder

Figure 2 Dual-lead worm and worm gear

A Duplex lead worm gear differs in module between the right and left tooth surface. While the pitch of the right and left tooth surface are different, the tooth thickness varies continuously. By shifting the worm axially, the tooth thickness at the working point will be varied, and the backlash of the duplex lead worm gears can be adjusted. There are some methods to adjust the worm in the axial direction. The simple and accurate way is spacer adjustment [5].

As Figure 4 shown, the poor contact results from locating distance error of the worm wheel. Here the contact shifts toward the worm wheel tooth's edge. The direction of shift in the contact area matches the direction of worm wheel locating error. This error affects backlash, which tends to decrease as the error increases [5]. The error can be eliminated by micro-adjustment of the worm wheel in the axial direction.

The procedure for assembly of rotary axis is described as followings.

(1) Assembly of dual-lead worm and worm gear.
(2) Assembly of the tapered-adapter-sleeve and dual-lead worm.
(3) The assembly error between the coupling-saddle and the dual-lead worm, in addition, it can use of micro-grinding diminished by spacer height (Figure 5).

As mentioned above, the micro-grinding of spacer height was trial and error method, which will reduce efficiency and increase costs. Therefore, in this study spacer has been designed as adjustment mechanisms to contribute effectively to the test and measurement.

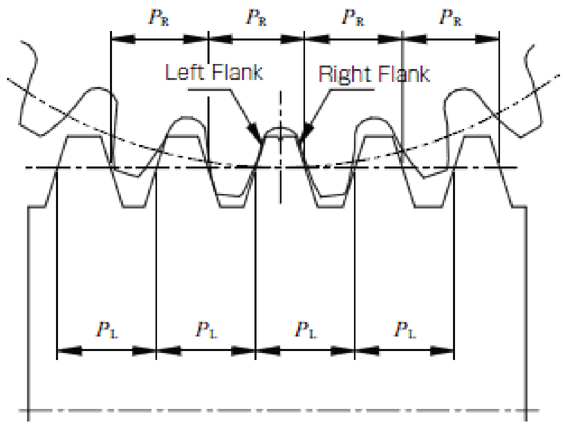

Figure 3 Duplex Lead Worm Gear [5]

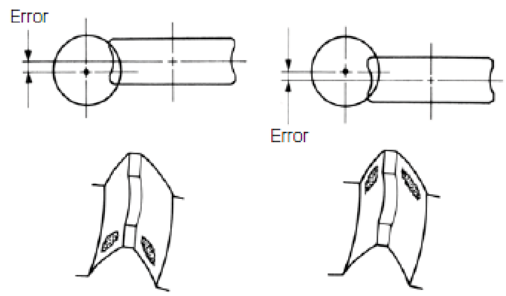

Figure 4 Mounting distance error [5]

3. MEASUREMENT SYSTEM

In this study, the development for the regulation during the assembly processing of the rotary axis is divided into two phases, as shown in Figure 6. The measurement system includes both adjustment of spacer height and real-time measurement indexing accuracy of worm and worm gear.

A measurement system is composed of hardware and software in the assembly rotary axis. The hardware includes adjustment mechanisms of spacer height, controllers, Linear Variable Differential Transformer (LVDT), rotary encoder and PC. Table1 lists the hardware specificities. The Visual Basic 6.0 software was used to develop the human machine interfaces of the measurement system for the rotary axis. Autodesk Inventor software was used to design the regulation spacer mechanism and encoder fixture mechanism, as shown in Figure 7.

The regulation spacer mechanism can be used for the displacement of vertical and horizontal. In addition, micrometer horizontal translation stage, regulation height between LVDT sensor-head and spacer can be utilized to adjust mounting distance and gap by the dual-lead worm and worm gear. Finally sequence mounting the coupling-saddle and servo motor are fabricated, as shown in Figure 8. The relationship between worm and worm gear for indexing accuracy can be realized by the rotary axis assembly and analysis of rotary axis error.

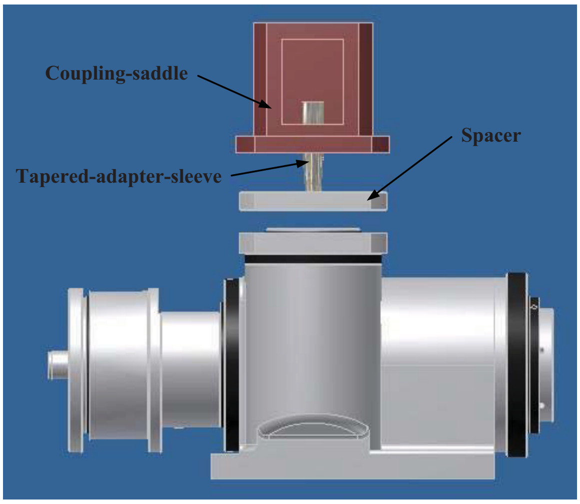

Figure 5. Assembly of spacer

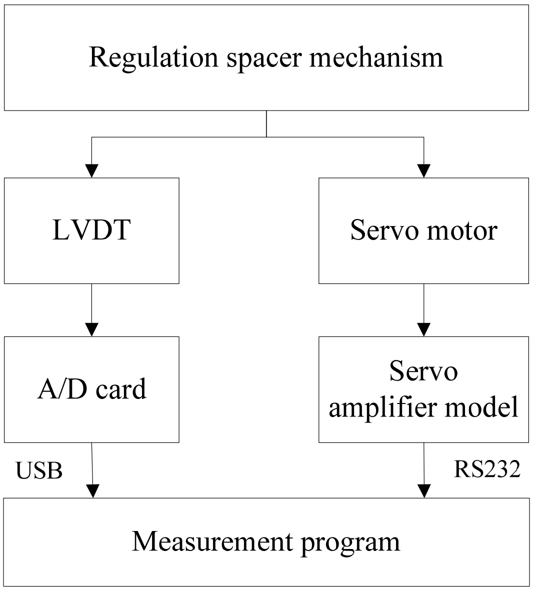

Figure 6. Signal procedure

Table 1. Hardware specificities

Model	Specification
CONTROLLER INTEK INCON-M450	X, Y, Z, 4th four axes close loop control with +/- 10V velocity command
SERVO MOTOR MITSUBISHI HC-KFS23	Resolution per encoder/servo motor rotation：131072 p/rev (10 arc seconds)
SERVO AMPLIFIER MODEL MITSUBISHI MR-J2S-20A	Resolution per encoder/servo motor rotation： 131072 p/rev (10 arc seconds)
Linear Variable Differential Transformer (LVDT) LVC2500	Resolution：0.1μm
Regulation spacer mechanism	floor space：372×260×300 mm
Encoder mechanism	floor space：200×60×250 mm

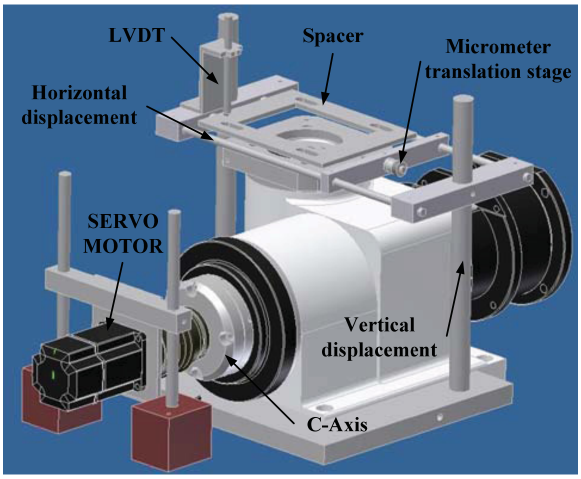

Figure 7. Assembly aided measurement system

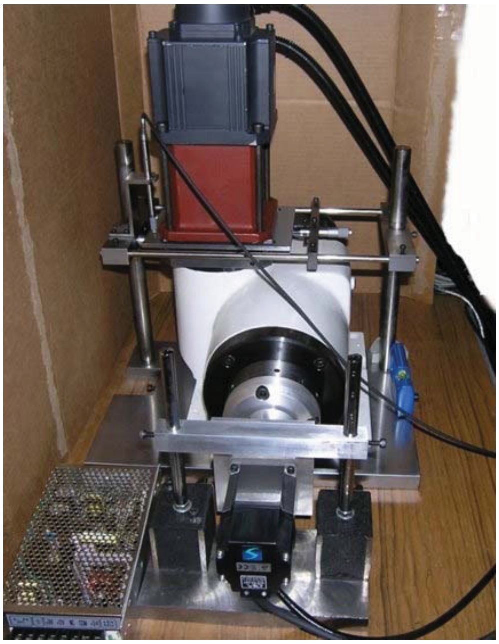

Figure 8. Rotary axis and measurement components

4. RESULTS

Design of regulation spacer mechanism is combined with measurement functions of LVDT and rotation encoder. By integrating output signals of measurement program, it can be provided how the regulation spacer thicknesses influence on rotation axis accuracy. The measurements of rotation axis accuracy are conducted according to the international standard ISO230-2.

The reason for the regulation spacer thickness range from 13 to 15 mm is from assembly program. With the spacer thickness of 15mm, Figure 9 indicates test results of C-axis positioning. The indexing accuracy range is from -110 to 260 arcsec and the inversion indexing accuracy range from 0 to 150 arcsec. The backlash of C-axis is inhomogeneous. This diagram reveals that with the spacer thickness of 15mm the indexing accuracy is worse.

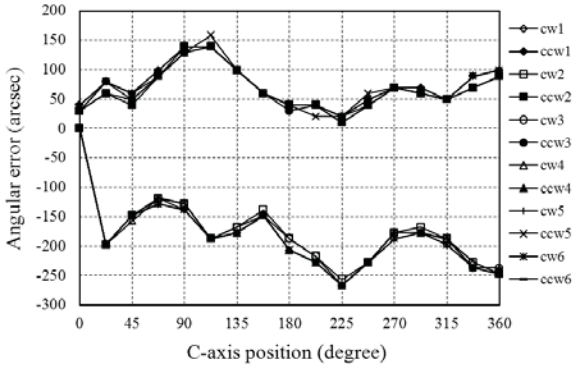

Figure 9. Test results of C-axis positioning (spacer thickness of 15mm)

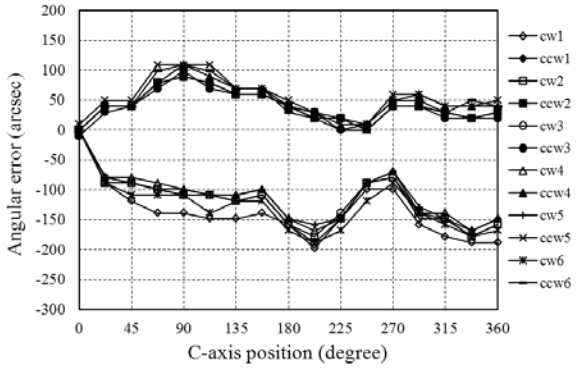

Figure 10. Test results of C-axis positioning (Spacer thickness of 14mm)

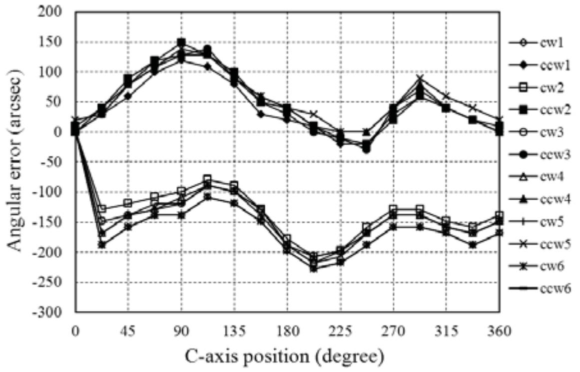

Figure 11. Test results of C-axis positioning (Spacer thickness of 13.8mm)

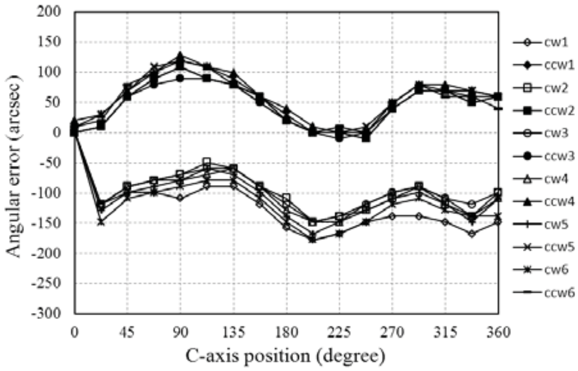

Figure 12. Test results of C-axis positioning (Spacer thickness of 13.6mm)

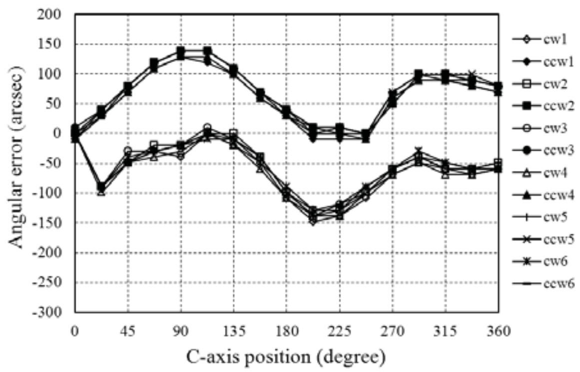

Figure 13. Test results of C-axis positioning (Spacer thickness of 13.4mm)

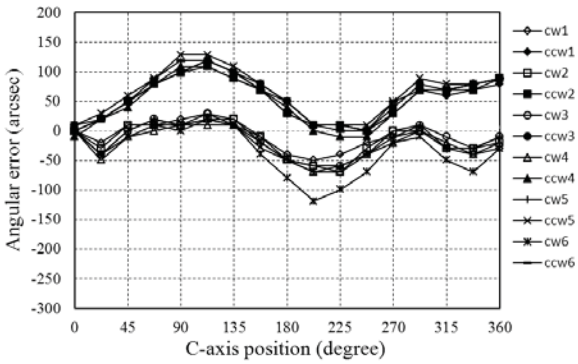

Figure 14. Test results of C-axis positioning (Spacer thickness of 13.2mm

Figure 10 indicates test results of C-axis positioning under the condition of the spacer thickness of 14mm. The indexing accuracy range is from 0 to 200 arcsec and the inversion indexing accuracy range from 0 to 150 arcsec. The backlash of C-axis is 250 arcsec. With the spacer thickness of 14mm, the indexing accuracy of 50 arcsec is improved in comparison with spacer thickness of 15mm. Figure 11 to 14 illustrates the curve of similar distribution for positive and inversion direction indexing accuracy. The results clearly show that lower spacer thickness has increased indexing accuracy and repeatability accuracy.

In Figure 15, with the condition of the spacer thickness of 13mm test results of C-axis positioning has been demonstrated. The indexing accuracy range lies from 0 to -100 arcsec and the inversion indexing accuracy range from 0 to 60 arcsec. The backlash of C-axis is 103 arcsec. This diagram shows that under the condition of the spacer thickness of 13mm, the repeatability accuracy is best.

With the condition of the spacer thickness of 12.88mm, Figure 16 demonstrates test results of C-axis positioning. The overlap of positive and inversion direction indexing accuracy, and then the repeatability is worse. The relationship between spacer thickness and accuracy error has been shown in Figure 17-20. The optimal regulation during the assembly processing of the rotary axis is in the order of mean bidirectional positional deviation, bidirectional accuracy of positioning and backlash.

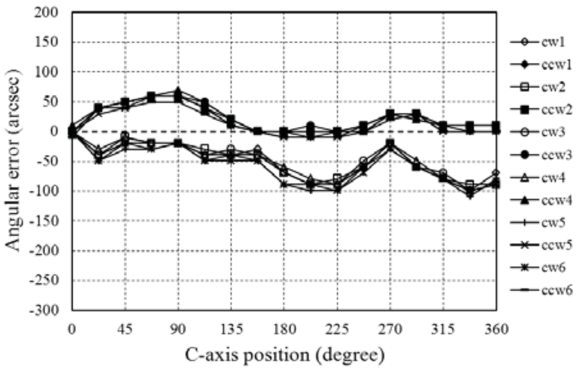

Figure15. Test results of C-axis positioning (Spacer thickness of 13mm)

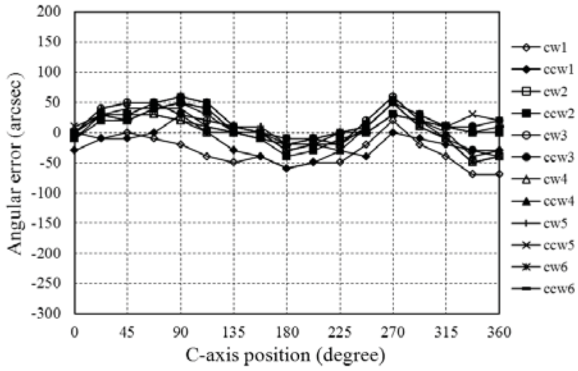

Figure16. Test results of C-axis positioning (Spacer thickness of 12.88mm)

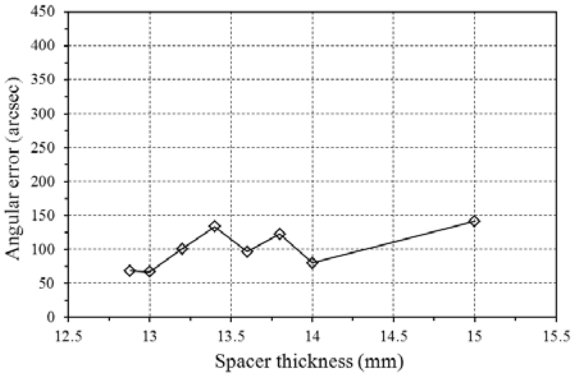

Figure17. Mean bidirectional positional deviation

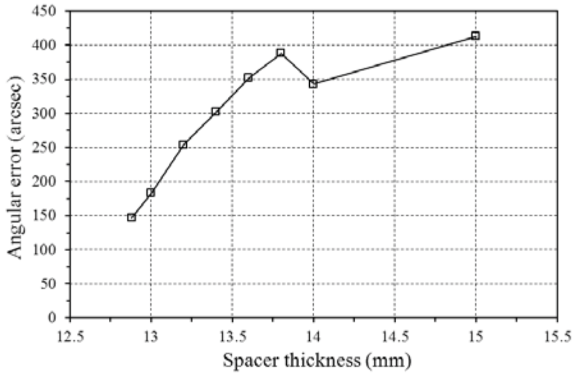

Figure18. Bidirectional accuracy of positioning

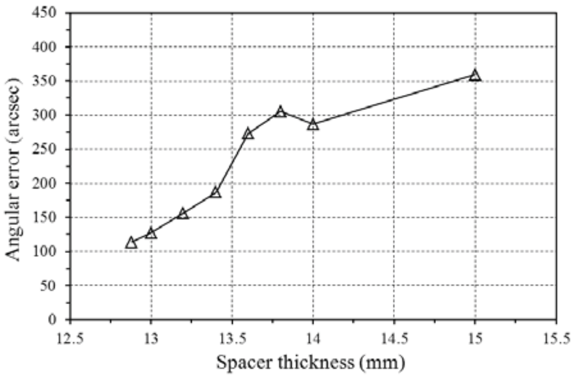

Figure19. Bidirectional repeatability of positioning

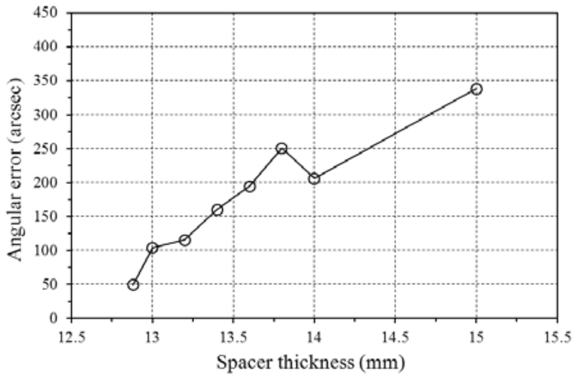

Figure20. Backlash

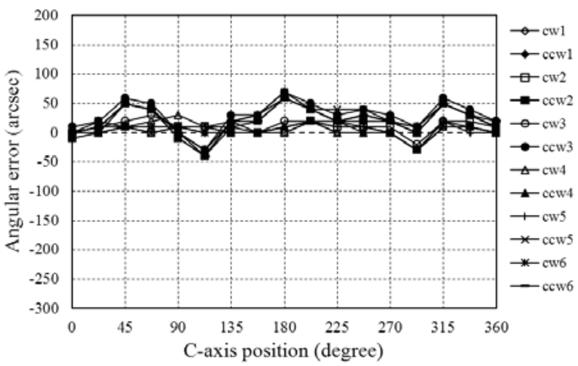

Figure21. Indexing accuracy after compensation

Form the above results, which are the results of Figure 15 (spacer thickness of 13mm), are optimal and that will be used for compensation. Figure 21 shows the rotary indexing error after compensation. The indexing accuracy range is from 0 to 30 arcsec and the inversion indexing accuracy range from 0 to 100 arcsec. Because of without compensation for inversion indexing accuracy, backlash compensation will be performed to reduce error range. Finally, the compensation accuracy of rotary axis has improved to 60 arcsec, in comparison with Figure 15.

5. CONCLUSIONS

In this study, the real-time measurement system for assembly of rotary axes in a tool grinder has been investigated and established. The results can be summarized as follows

1. The experimental results indicate the maximum rotary indexing error is at the position of 202.5° and for the inversion at the position of 90°.

Therefore, regulation of spacer thickness is not the major factor influencing the precision. The manufactory accuracy for worm and worm gear should play the most important role on the determination of rotary indexing error.
2. A key factor in tool grinding is the backlash of worm and worm gear. In this respect the backlash has a correlation with the accumulation of tool grinding time.
3. The improvement of indexing precision can be verified by the comparison analysis between the rotary indexing error before and after compensation.

6. REFERENCES

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